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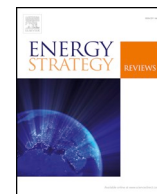
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Energy and the military: Convergence of security, economic, and environmental decision-making

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ABSTRACT

Energy considerations are core to the missions of armed forces worldwide. The interaction between military energy issues and non-military energy issues is not often explicitly treated in the literature or media, although issues around clean energy have increased awareness of this interaction. The military has also long taken a leadership role on research and development (R&D) and procurement of specific energy technologies. More recently, R&D leadership has moved to the energy efficiency of home-country installations, and the development of renewable energy projects for areas as diverse as mini-grids for installations, to alternative fuels for major weapons systems. In this paper we explore the evolving relationship between energy issues and defense planning, and show how these developments have implications for military tactics and strategy as well as for civilian energy policy.

1. Introduction

1.1. Military decision-makers confront an interconnected range of energy challenges

Nations and organizations face an energy trilemma, which combines concern for energy economics and affordability with a desire for environmental protection and assured energy security. Addressing all three considerations together has proven to be a difficult challenge for energy policymakers. In this paper, we address the interface of defense policy and energy policy—the relationship between defense policy (including for technological innovation) and energy supply and use. This domain of concern is linked to issues sometimes referred to as “energy and security”, which is separate from the notion of “energy security” as conventionally conceived. Energy and security, as discussed in this paper, involves the role of energy technology and policy and its influence on military mission objectives.

The drivers for energy decision-making in the non-military sectors of the economy are largely economic. The energy system consists of mostly privately-owned energy assets interacting with public policy and regulatory frameworks to ensure economic competitiveness and social welfare via energy affordability, to provide reliable energy access and services (sometimes termed “energy security”), and to adhere to environmental regulations and goals in areas such as climate change, air

pollution, and water quality. The core of the concept of energy security in a globalized energy market is represented by attempts to reduce the negative impacts of supply and price shocks through efficiency, diversified supplies, and fuel choices [1], although many other expanded indicators of energy security are often used [2–8]. “Environment” is represented by state, federal and international efforts to minimize air, water, and waste impacts associated with energy, and to encourage new energy sources with fewer greenhouse gas (GHG) emissions. In military energy decision-making, the underlying economic, security, and environmental drivers of energy decision-making exist, but the military translates and applies these concepts very differently. In the domain of defense, energy has the potential to be both an enabler of hard power but also, via denial, arguably itself to be a weapon of war. One of the motivations for this paper is to make clear that conventional paradigms of energy security (relating to economic prosperity and social harmony) should not be confused with security in the military-energy nexus (focused on the potential for hard power and willful coercion). Defense energy and security efforts are more directed at achieving military mission and strategic objectives.

Energy considerations have long been essential to mission delivery of armed forces worldwide. These include operations in theater of conflict, for land, air, and water transport, and for installations and forward operating locations. More recently, the topic has risen around clean energy and new challenges facing the military [9–22]. Energy

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enables nearly everything the military does, and the primary objective is mission assurance and decisive advantage on the battlefield. So “security” is derived through energy powering capable major weapons systems and communications infrastructure at the desired levels of performance, range, and readiness. But resupplying energy to combat theaters and the battlespace edge is a vulnerability, so security is also derived through minimizing the energy required for vehicles and forward locations. Reducing and diversifying fuel use are also drivers behind economic considerations of military energy use. The US Department of Defense (DoD) is the largest US government user of energy [23], and within overall constrained budgets volatile energy costs represent a source of a risk to military operations and maintenance needs. Finally, defense policy makers must choose paths that strengthen environmental performance objectives, which in the US are driven by Departmental and Federal guidelines. Environmental performance also contributes to maintaining DoD's social license to operate. That social license might represent an engagement and maintenance of support with host communities, whether home or abroad.

The world's militaries have also for more than a hundred years taken a leadership role in research and development (R&D), and procurement of emerging technologies – especially where they are applicable in combat theaters [24–27]. Over many decades that leadership has involved issues relating to energy supply and use. Recently this interest has expanded to include stronger consideration of resource efficiency and environmental impacts. There has been increased emphasis on the efficiency of home-country installations, and the development of unconventional energy projects, including renewables, for areas as diverse as micro-grids and mini-grids for installations, to alternative fuels for major weapons systems such as aircraft and ships. Different countries are approaching the evolving military-energy challenges in different ways and with different emphasis. In this paper, we emphasize the policies and actions of the United States (US) given its current globally leading role in defense. We also consider some earlier historical British experiences. We also comment on the role of energy considerations in the work of the United Nations, particularly in peacekeeping operations.

For our analysis of the US government and military, we mostly focus on the period 2009–2011. We chose this period because it represents a peak in real enacted US defense expenditures. Real US defense expenditures rose sharply after the terrorist attacks of September 11, 2001 to support overseas contingency operations in Afghanistan and Iraq, before peaking in FY2010 and then declining [28,29]. We note that recent U.S. DoD enacted budgets in Fiscal Year 2018 and 2019 have been higher than in 2013–2017 [30]. However, here we focus on the 2009–2011 period of real maximum expenditure.

Military decision-making under the confluence of these security, economic, and environmental objectives, has over decades coalesced to create a new and adaptive energy policy for the DoD, and hence for the United States. This confluence of objectives will continue to shift the technologies and strategies that will be used to power the military, and which, in time, can be expected to shape civilian technologies as well.

1.2. Defense and civilian energy

Despite our claims for defense exceptionalism, in some scenarios, the military concerns of defense and energy can collide with civilian energy security issues. One point of contact relates to energy prices as faced by defense agencies and ministries, but the challenges can run deeper. For instance, The International Energy Agency (IEA) was established in November 1974, after an economic and political crisis in 1973–1974. The crisis emerged from the 1973 ‘Yom Kippur’ war and the oil embargo response of the Organization of Arab Petroleum Exporting Countries (OAPEC). OAPEC was distinct from ‘OPEC’, a broader body established earlier in 1960, including, for instance, Venezuela and other non-middle eastern states. The industrialized west

had become dependent upon petroleum imports from Arab countries and in the face of OAPEC production cuts, prices rose dramatically [31].

As Scott [31] notes: *“The industrial countries permitted excessive and even wasteful and inefficient use of energy and of oil in particular. Energy conservation measures in those countries were woefully underdeveloped. Their oil production potential was not fully realized, nor was sufficient investment devoted to the development of other energy sources as alternatives to oil. They had yet to devise a workable system for responding to serious disruptions in oil supply; and their organizational arrangements for co-operation could not enable them to cope effectively with the institutional implications of those situations.”*

The IEA itself is based upon an international treaty: The International Energy Program Agreement of 1974 and amended in 1992. The measures included a legally binding oil sharing mechanism and the creation of a strong Secretariat based in Paris. Chapter 6 of the Agreement established a “framework of consultation with oil companies”. The IEA member states are required to maintain strategic petroleum reserves among which, the US has the largest. Formally, IEA members operate their strategic petroleum reserves autonomously and may use their stocks for national purposes [31]. US emergency draw-downs from its Strategic Petroleum Reserves have historically been coordinated with the IEA [32]. The primary purpose of IEA strategic petroleum reserves is to stabilize global markets in times of turbulence. Coordinated release can meet market demand during supply disruptions to reduce price volatility. Arguably such planning lies within the conventional paradigm of energy security. There is however the potential for another dimension to the existence of strategic energy reserves. One can easily imagine conflict scenarios threatening energy supply chains such that military planners might wish to conserve strategic reserves and use them to meet military energy needs. Any desire to retain stocks in the face of system stress would run directly counter to the economist's preference to alleviate supply scarcity in the market. Additionally, for countries with domestic oil production such as the US, it is likely that under such a scenario the military would be the first buyer of any domestically produced fuels, and the US Defense Production Act enables the President to prioritize energy procurement for national security [33].

It would be incorrect to assume that the world of defense energy and security is full of change and uncertainty while the civilian concerns of energy security are more static and stable. Not so very long ago US political rhetoric concerning “energy independence” appeared to be merely fanciful and populist. The revolution in natural gas and oil production in North America arising from the hydraulic fracturing and horizontal drilling of shale deposits has in a few years utterly transformed the energy landscape of the United States. The US has gone from being a predicted major importer of oil and natural gas to a prospective major exporter [34]. The long-term consequences of this shift for the world of energy and defense remain to be seen. Two important possibilities are in prospect. First, the potential creation of a free-standing global spot market for natural gas independent of the oil market, and second, a shift in the security challenges of the United States in seeking to stabilize that emergent global market alongside an oil market of diminishing direct relevance to US interests.

Historically, defense-related research and development has affected technological change in broader areas of the economy [24], but requires specific organizational structures to fully realize many of these spillovers [35]. Civil aviation has been built upon a series of twentieth century military innovations, many forged in conflict. These include: gas turbines (jet engines), airframes, radar, cabin pressurization, de-icing, and many more [24,36–38]. In space, the reliance on satellite-based technologies in communications, geo-positioning and earth observation (e.g. weather forecasting) were all made possible by government and military R&D and procurement in rocketry and space-based technologies of nuclear deterrence [27,39]. In this paper, we posit a looming transformation in energy both military and civilian domains.

1.3. Structure of the paper

The remainder of the paper is organized as follows: Section 2 briefly discusses historical energy drivers for the military and the energy impetus included in modern defense planning. Section 3 describes DoD operational and installation energy, and expounds on the evolving confluence of military energy policy. Section 4 provides conclusions and observations. While we will highlight the factors shaping the energy and defense agenda, we exclude from consideration in this paper the ways defense planning will adapt to incorporate climate change impacts (see, for example, [40]). Climate change impacts can be direct, such as changes to surface shipping routes and military logistics or affecting military installations [41–44], but could also be indirect, such as increasing regional pressures on natural resources and potentially accelerating conflict [44,45]. Scholars are continuing to assess the strength of the links between climate change and conflict [46], and we and others will examine aspects of such matters in future work. But here we simply concur with former U.S. diplomat and national security adviser Leon Fuerth when he observes;

“In the realm of military thinking, it is standard practice to consider worst-case scenarios as a way to avoid settling on insufficiently robust courses of action. Also in military thinking, it is standard to pay serious attention to low-probability, high-damage events (e.g. nuclear war). Where climate change is concerned, however, our thinking tends toward best-case outcomes, for no real reason other than the inconvenience of the possible truth. Planning for climate change needs to shift toward worst-case scenarios, especially because trends in the physical evidence are all pointing in that direction.” [47].

2. The past and present of Energy's role in defense planning

2.1. Historical linkage of war and energy

Energy has played a role in every facet of war from troops in garrison and defensive planning to mobilization and attack. The need to deliver adequate and timely energy supplies to military forces—particularly to those in the most forward-deployed locations—has long existed as a strategic vulnerability to the success of military campaigns. Targeting materiel supply channels in an effort to reduce adversaries' operational strength has often been employed as an effective tactic. In addition, the logistics to deliver a reliable energy supply has been a recurring theme in the story of both successful and unsuccessful military operations [22].

Many of the lessons learned during the world wars of the 20th century are still being appreciated and relearned in today's conflicts. One of the most famous examples of energy influencing military strategy comes from 1911, when Winston Churchill, then First Lord of the Admiralty, converted the British fleet from Welsh coal to foreign oil. The resulting gain in speed and decrease in logistical burden gave the British Royal Navy a critical advantage over the Axis powers [48]. The action proved decisive and enabled the allied power to “float to victory on a sea of oil” [49]. The policy brought with it further advantage as the less smoky combustion of oil allowed the Royal Navy to avoid producing the tell-tale plume of dark coal smoke that could so easily reveal a fleet's position [50]. In parallel to British developments, the shift from coal to oil was also underway in the smaller United States Navy throughout the First World War, but powered by domestic oil (primarily from Oklahoma, Texas and California) [51].

While the shift from coal to oil was a decisive one for Winston Churchill and for the Royal Navy, the history of the First World War further reveals its status as the first major conflict fought, in part for energy. British strategy, reinforced by the Battle of Jutland (May 31st to June 1st 1916), relied on a blockade denying Germany and its allies access to global supply chains including most notably food, but also oil

and other industrial resources. Even before the war, there had been a competition for access to Persian Gulf oil with, on the one hand Germany seeking to establish a Berlin to Baghdad railway, and on the other Britain establishing commercial oil operations in the region, among which Anglo-Persian Petroleum was the most prominent [52]. During the war, access to oil became a pressing concern for both sides. According to Paul [53], Secretary to the British War Cabinet Sir Maurice Hankey went so far as to say about Mesopotamian oil that “Control of these oil supplies becomes a first-class war aim”. Following victory, Britain and France initially divided access to all Mesopotamian oil between them, but then the British out-maneuvered France going into the Versailles peace conference and secured exclusive access to Mesopotamian oil via a new League of Nations protectorate called Iraq [52,53].

As the militaries of the world shifted during the early twentieth century toward oil as the main energy source, energy security and geopolitical positioning became important planning and operational variables. The resulting scramble to secure oil supplies heavily influenced events leading to and throughout WWII. Some of the greatest military strategic decisions in World War II had their roots in a desire to access energy resources. Operation Barbarossa – Nazi Germany's failed invasion of Russia (June–December 1941) is frequently presented as an attempt by Hitler to access Soviet oil resources. Germany later captured the Maikop oil field in November 1942, but was overstretched and lacked the equipment to bring the field back into production [54]. The German military's perceived need for oil created a two-front war and their failure to take and hold the oil fields spelled disaster at Stalingrad and changed the tide on the eastern front [55].

In the Asia-Pacific theater, the need for oil and other resources shaped Japanese military and foreign policy both before and during the war. Much like the surprise attacks in operation Barbarossa, the Japanese surprised the American naval fleet on December 7, 1941 in an attempt to secure oil shipping lanes [55,56]. Previously, at the initiative of US Secretary of State Dean Acheson, the US had effectively blocked oil exports to Japan in July 1941 following Japan's invasion of French Indochina which in turn had followed Germany's defeat of France in Europe. Fearing that any mitigating response would prompt conflict, Japan decided to act aggressively and near simultaneously attacked Pearl Harbor in the Central Pacific, Hong Kong, and Malaya [56]. These attacks were at the heart of a Japanese strategy to secure oil and other natural resources, such as rubber, from South East Asia. Japan used the term “Southern Resource Area” to describe its sphere of wider influence [57], while true vassal states joined the Greater East Asia Co-Prosperity Sphere. As such, Japan's assertion that it was ridding the region of European colonial rule surely had a rather hollow ring.

Energy's link to conflict in WWII had as much to do with the denial of resources to the enemy as it did to securing one's own oil supply chains. The stalling of General Patton's Third Army following its campaign across France in August and September 1944 is a telling example of fuel acting as a “tether” to military operations [58]. At the time, Patton's army was more than 100 miles closer to Berlin than any other Allied army. While Patton had the advantage on the battlefield, he the disadvantage of being tethered to an energy source located hundreds of miles away. Years later, in 1970, war strategist Sir Basil Hart described the delay as the “unforgiving minute” and that the “best chance for a quick finish”, to the war, “was probably lost when the gas was turned off on Patton's tanks.” [55].

While the skill of logistics forces in providing fuel has grown significantly since World War II, many leaders in the military are mindful of the operational implications of fuel's logistical requirements. General James N. Mattis (Retired) highlighted the enduring criticality of logistics—energy logistics in particular—when he echoed the call of General Patton and entreated the U.S. DoD to “unleash us from the tether of fuel” as a result of his experience leading U.S. Marines into Iraq in 2003 [59]. A test deployment in 2010 of portable solar-powered generation systems at U.S. Marine forward operating bases in Afghanistan reduced

the bases' diesel generator usage by more than 90%—drastically reducing the need for risky and costly fuel convoys to keep these bases supplied with energy [60].

The Twentieth Century saw energy figure ever more centrally as a driver of conflict, a strategic factor and a tactical consideration in war. The trend extended through the end of the Twentieth and into the Twenty-first Century. For example, the energy intensity of war fighting grew by a factor of 16 and the oil-intensity of the individual soldier rose 2.6% annually from 1970 to 2010 [61]. This military evolution and decades of technological innovation has, until very recently, not substantially reduced the mission-criticality of fuel supplies. For this reason, it has become an important area of research, development and defense planning.

2.2. Energy and modern defense planning

There is a vast and evolving literature on energy security as seen from the perspective of civilian energy policy-makers the framing of such considerations, and frequently gives emphasis to the concerns of energy economics and involves notions of security of supply and security of demand for those involved in energy-based trade. Here we focus on defense energy and security—those instances where energy is directly related to armed conflict, the threat of such conflict, military facilities, or concerns in the clear confines of foreign diplomacy. In the Twentieth Century, this was primarily associated with the global oil sector or the use of fossil fuels for troop movements, although the story of the use of nuclear energy for submarine warfare and naval nuclear deterrence is another important example of defense-energy synergies. The high energy density of nuclear fuel made possible the strategic doctrine of Continuous At Sea Deterrence (CASD) in which Ship Submersible Ballistic Nuclear (SSBN) submarines hide in deep blue water awaiting orders from the Commander in Chief to move to launch depth and deploy the onboard missiles. The nuclear reactor made possible the ultimate second strike nuclear weapons system able to deliver massive retaliation consistent with either counter-force or counter-value goals. Meanwhile ranged against every SSBN force are a set of nuclear-powered attack submarines designed to neutralize an enemy deterrent early in a conflict. Arguably this whole defense enterprise was enabled by an energy technological innovation – the controlled nuclear fission reactor.

2.2.1. Geostrategic risk

The need to secure oil supplies and to maintain the stability of world oil markets has played a major role in shaping US foreign policy and dictating US military strategy and deployment [62,63]. While DoD's own petroleum demand is a relatively small portion of US petroleum needs, it experiences a unique feedback loop in adding to the energy and defense concerns that arguably have partially motivated US military action in the first place.

2.2.2. Increased dependence

The international, US-led, operations in Iraq (since 2003) and Afghanistan (since 2001) have illuminated the increased cost and intensity of energy use in modern theaters of conflict. In World War II, the United States consumed about a gallon of fuel per soldier per day, in the 1990–91 Persian Gulf War, about 4 gallons of fuel per soldier was consumed per day. In 2006, the US operations in Iraq and Afghanistan burned about 16 gallons of fuel per soldier on average per day, almost twice as much as the year before [48].

2.3. Energy and defense - the role of the United Nations

The United Nations (UN) has had a leading role in attempting to mitigate climate change caused by human activities. In Rio de Janeiro

Brazil in 1992, the UN created the Framework Convention on Climate Change, which was followed in 1997 by The Kyoto Protocol. The intention of the Convention [64] (UNFCCC, 1992) was that major developed industrial countries would lead the way in greenhouse gas emissions reductions. Developing countries, most notably China, were exempt from any obligation to limit or reduce emissions and the United States, although a signatory to the Convention never ratified the Kyoto Protocol. While one might argue that global emissions are lower than they would have been in the absence of the Convention, the Protocol and UN concern generally, it is clear that this high-profile UN initiative has so far failed to live up to the early expectations of its proponents.

Global environmental protection was not a founding mission of the UN—it was conflict prevention that motivated and shaped the UN's mission. It was conceived by the Allied Powers in 1942 in the depths of World War II in a *Declaration by United Nations* [65], and the UN charter reveals an ongoing focus on international peace and security [66]. In the domain of defense energy and security, it is in UN work to support the core function of peacekeeping that one can find tangible examples of environmental progress.

2.3.1. UN peacekeeping

UN Peacekeeping is noteworthy for the explicit policy consideration given to the minimization of negative environmental impacts. While military forces devoted to warfighting must necessarily prioritize narrow military objectives, the special focus of peacekeeping operations permits, and arguably even requires, a different balance of priorities in what is fundamentally a military enterprise.

UN peacekeeping operations consist of around 115,000 staff in 16 countries (at the end of 2012) and represent 55% of the emissions of the entire UN system [67]. The largest share of emissions for peacekeeping operations is due to air travel (46%), followed by power generation (26%) and road vehicles (15%). Until 2009, the decisions regarding the adoption of renewable energy sources and of energy efficiency measures were generally handled at the single mission level, lacking any general UN-wide policy in the area, despite the potential for cost savings [68].

The UN then initiated a policy of reduction of its environmental impact in all of its operations, including its energy consumption for the field missions, and to pursue also other environmental goals following the spirit and the indications of the Seventh Millennium Development Goal (MDG7) to ensure environmental sustainability. Two instruments have been adopted: the first is the *Environmental Policy for the UN Field Missions*, adopted by the Department of Peacekeeping Operations (DPKO) and by the Department of Field Support (DFS), the second is a *Global Field Support Strategy* adopted by the General Assembly [68,69,111]. These policies are mandatory and include many areas of the environmental sustainability of peacekeeping operations, including camp management issues (such as the use of water, wastewater, solid and hazardous waste, wildlife, and energy). The adoption of these policies provides minimum environmental standards and operational guidance for all field missions.

The United Nations Environmental Programme (UNEP) affirmed that one obstacle to the adoption of energy efficiency and renewable energy technologies in the field is that the field mission's length is often unknown in advance and consequently a future-oriented cost-benefit analysis of renewable technologies becomes difficult [68]. In many cases the technologies to be deployed are chosen on the base of the initial length of the mission, typically six to twelve months, while the average length of a mission is far longer, typically seven years. Experience from the implementation in UN peacekeeping operation of sustainable energy and energy efficiency measures points to a cost-recovery payback time of one to five years [68]. The benefits that surely exist are being missed as a result of an excessively short-term mindset in project planning and approvals. Part of the solution could be to allow

for time horizons to be considered for cost benefit analysis that exceed the authorization period of the mission in question at the time of assessment.

There have been some successful cases of sustainable energy intervention in UN peacekeeping operations. The mission in Timor-Leste (UNMIT) established an environmental committee that monitored energy use and adopted energy efficiency measures, including staff practices, and used solar energy for isolated applications. These practices led to a saving of around 335,000 USD per year. The UN Interim Force in Lebanon (UNIFIL) has implemented the UN's 2009 policies: putting in place environmental guidelines and an action plan for the mission, and a complete Environmental Management System (EMS) that manages all environmental related aspects of the mission. The measures adopted include the introduction of efficient transport vehicles, efficient electricity generators and building chillers, and the implementation of solar PV generation. In Darfur, UN-African Union Hybrid Operation in Darfur (UNAMID) forces have helped local women with their energy needs and security, escorting them regularly when collecting wood for fuel outside the camp, and also introducing efficient cook-stoves reducing the consumption of firewood by up to 80%. These measures greatly reduced the risks of assault and violence for the women, particularly during the agricultural cultivation season [68].

Notwithstanding these cases, UNEP notes also that the new policy guidelines are still to demonstrate sufficient results on the ground, and UNEP further stresses the importance of an initial focus on training, monitoring and reporting activities and of the creation of an Environmental Baseline Studies and of Environmental Impact Assessments for field missions. Furthermore, UNEP suggests that a dedicated environmental officer should be appointed to each mission and that this person should report directly to senior level staff.

The extent to which UN concern for environmental impacts in peacekeeping is linked to the role of the organization is attempting to enhance global sustainability and a low-carbon future can be debated, but it is clear that the desire to be seen to lead by example is underpinning actions by the UN to reduce the harmful environmental impacts of its own activities.

2.3.2. Energy and defense in a military alliance - NATO

The NATO approach to energy issues is taken through an energy and defense lens, both for its member countries and of its operations. NATO debated its approach to "energy security" in 2006, and convened this theme to be of central importance for the alliance and further mandated its member countries to define its role¹ [70–73]. One of the consequences of this decision is that a NATO Energy Security Centre of Excellence was founded in Lithuania (NATO ENSEC COE) in 2012. The Centre will join the family of the other NATO COE and will provide 1) strategic analysis and research; 2) development of doctrine, standards and procedures; 3) education, training and exercise and 4) consultations [74]. Some work in this area has already started, in particular NATO members are collaborating to exchange smart energy solutions to reduce fossil fuel consumption in their respective militaries, and reduce the threat to the environment [75].

The problem of fuel consumption and of the security of fuel supplies has particularly affected the largest NATO operation in history Afghanistan. In late 2012 ISAF forces amounted to more than one hundred thousand troops consuming more than 1.8 million gallons of

fuel (6.8 million liters) every day, 99% of which delivered by truck from abroad. The fuel travelled through Pakistan but, after an air attack that accidentally killed 24 Pakistani soldiers in 2011, the border was closed by the Pakistan government and NATO forces were forced to shift all the supply of energy to the North, through the Northern Distribution Network (NDN), a rail link of more than 5000 km starting from Latvia, traversing Russia, Kazakhstan and Uzbekistan until the city of Termez, where trains are offloaded and the fuel is moved to trucks that cross the border to Afghanistan.² It should not have come as a surprise when Foreign Policy described this logistic network as a "nightmare" [76–78].

The long-standing vulnerabilities and difficulties of fuel logistics seen in World War I and World War II are so far undiminished despite enormous progress in military technology. In fact, in some aspects these vulnerabilities have grown as the energy intensity of conflict has increased.

2.4. Positing the prospect of a future revolution in military affairs

As in previous conflicts, the U.S. military has used technologies and strategies to adapt to the new challenges experienced in the wars in Afghanistan and Iraq. The rapid increase in use of remotely piloted aircraft (aka "drones") in these theaters signaled a realization of the "revolution in military affairs" that drones represented (see, for example [79–81]). A revolution in military affairs, or RMA, "involves a paradigm shift in the nature and conduct of military operations" [81,82]. The literature cites many past examples of RMAs that have changed warfare, including precision strike munitions, nuclear weapons, the aircraft carrier, radar, and even the English-developed longbow from the thirteenth century. RMAs can be technological, but can also result from the emergence of new strategies, doctrine and decision-making [81]. We argue that the new ways that the military plans for, uses, and manages energy could represent a future RMA that could transform DoD acquisitions and operations, and enhances the capabilities of the fighting force. In this way, the military would break free of the risks and difficulties seen in conflicts over at least the last 100 years.

As we have seen, resupplying energy to combat vehicles and the warfighter has long been a vulnerability and area of desired improvements by the military. Throughout the military literature, there has long been a desire of enhancing the ratio of the fighting "tooth" of the military to the supporting logistics "tail" (see, for example [40,83,84]). The size and requirements of the tooth of the fighting force directly affect the size and requirements of the resupplying tail. For example, when combat vehicles and warfighters deploy to theaters, they require additional vehicles and personnel as combat support elements (such as medical, supplies and other needs), and these combat support elements, themselves require resupply from other combat service support elements along the tail. This results in cascading vehicle, personnel and supply requirements from the tooth to the tail. In World War II, average fuel demand per soldier was about 1 gallon per day. As noted earlier, this has increased to 15 to 20 gallons per soldier in Operation Iraqi Freedom and Operation Enduring Freedom [85]. The long-standing challenges of fuel logistics are undiminished and arguably becoming worse. The vulnerability of such supply lines was exploited by enemy fighters, and contributed to about one U.S. Marine Corps casualty for every fifty convoys in Afghanistan [86]. A separate estimate [87] distinguished FY (Fiscal Year) 2007 Army soldier and civilian casualties by energy and water convoys. In Iraq, the Army study found 1 casualty for every 39 fuel convoys and every 63 water convoys. For, Afghanistan the casualty factors were higher- 1 casualty for every 24 fuel convoys and

¹ Article 45 of the NATO Riga declaration in 2006 states that: "As underscored in NATO's Strategic Concept, Alliance security interests can also be affected by the disruption of the flow of vital resources. We support a coordinated, international effort to assess risks to energy infrastructures and to promote energy infrastructure security. With this in mind, we direct the Council in Permanent Session to consult on the most immediate risks in the field of energy security, in order to define those areas where NATO may add value to safeguard the security interests of the Allies and, upon request, assist national and international efforts."

² Another route of the NDN bypasses Russia, starting with the Georgian port of Poti, and goods travel through Azerbaijan, the Caspian Sea, Kazakhstan and still reach Afghanistan through the Termez bottleneck in Uzbekistan.

every 29 water convoys [87]. These casualties incurred during resupply have intensified DoD's efforts to reduce this strategic security vulnerability. Reducing energy and water requirements for the fighting tooth represents a significant and realizable opportunity to shift the fundamental tooth-to-tail ratio in the Armed Services.

Two other factors have recently shaped military energy decision-making. The first is the increased focus on the costs of military energy. In FY 2011, DoD consumed 939 PJ (890 trillion British thermal units or BTU) of energy, which was approximately 1% of U.S. energy consumption and 80% of U.S. federal energy consumption [88], at a cost of \$19.3 billion [89]. DoD spent approximately 90% of these FY2011 energy costs on petroleum products. In FY2011, DoD consumed roughly 117 million barrels of petroleum (Schwartz et al., 2012), approximately 2% of total U.S. petroleum consumption in 2011 [88]. In FY 2011, jet fuel alone accounted for nearly 60% of total DoD energy consumption, while all petroleum-based fuels supplied about 80% [88]. Despite a 4% decrease in DoD's petroleum consumption between FY 2005 and FY 2011, the agency's petroleum expenditures over the same period rose 381% in real terms due to rising oil prices [90]. While still a relatively small portion of DoD's total spending (2.5% in FY 2011), the \$17.3 billion spent on fuel in FY 2011 is large in absolute terms. In the two decades after 1990, the DoD's cost of buying fuel increased faster than health care, personnel and every other major DoD budget category [90]. Additionally, petroleum price volatility has negatively affected DoD operating budgets and created large unfunded obligations [90].

The second other factor affecting military energy decision-making is the requirement for the DoD to improve energy efficiency, use renewable energy, and energy management as directed through several legislative and executive actions. From the National Energy Conservation Policy Act enacted in 1978 to the Energy Independence and Security Act of 2007, to Executive Order 13514 signed in 2009, a bevy of federal mandates have sought to demonstrate the federal government's own leadership in fostering sustainability and reducing greenhouse gas emissions by setting aggressive goals for federal agencies. These goals are aimed at reducing water and energy intensity and petroleum consumption, and at increasing the use of renewable, efficient, and alternative energy technologies. These goals and mandates range from requirements to develop and implement energy and water management strategies; efficiency standards for acquisition of new energy-consuming products, equipment, and vehicles; and percentage targets for the use of renewable energy-generated electricity. Additionally, several of the annual National Defense Authorization Acts (NDAA) that fund the Department of Defense have included Congressional language that affects energy use in weapons platforms as well as on installations.

It is clear that the dependence of US military operations of extended and vulnerable fuel supplies is unsustainable on many levels. A Revolution in Military Affairs could arise whereby innovative technology in energy supply and use could reduce the need for extended fuel supply lines. Reduced external energy needs through device, motor, and housing efficiency and distributed energy resources at combat outposts and forward operating bases could reduce the amount of transported fuel required to serve these locations. Increased efficiency of tactical and non-tactical vehicles could further reduce the logistics needs of fuel resupplies. These technological innovations will be driven by defense policy and military needs and as such will be largely independent of measures to promote energy technology in the civilian sector. The consequences for civilian energy supply and use arising from defense innovation could, however, be significant.

2.5. US trajectory in operational military energy decision-making

The DoD separates energy consumption into facility (or installation) energy and operational energy, since each possess distinct characteristics, priorities, and opportunities. Facility energy is consumed at fixed installations and by non-tactical vehicles [89]. Operational energy is defined in law as "the energy required for training, moving, and

sustaining military forces and weapons platforms for military operations." [91]. Although some ambiguity exists in the delineation between these two categories, DoD's FY2011³ energy consumption was roughly 74% operational energy and 26% installation energy [89]. The proportion of operational to installation use depends greatly on the current level of military activities. High levels of operational use in the first decade of this century reflect U.S. operations in Afghanistan and Iraq [90]. In FY 2011, DoD consumed roughly 686 PJ (650 trillion BTU) of operational energy, of which the vast majority was supplied from petroleum-based fuels [89]. Estimates for DoD petroleum expenditures in FY 2011 range from \$15-\$17 billion [89,90]. The Air Force consumed the most petroleum (53% in FY 2011), followed by the Department of the Navy (28%), including the Marine Corps, and the Army (18%). All other DoD agencies accounted for the remaining 1% [90].

A DoD presentation [92] identified operational energy processes and levers DoD can influence, including:

- Force Planning Assumptions and Defense Planning Scenarios
- Requirements Development
- Acquisition Programs and Rapid Fielding
- Technology Priorities and Investments
- Culture, Measurement, Education and Billing

DoD's petroleum consumption (and especially its volume, disproportionately growing cost, and additive effect to geostrategic risks) has been widely discussed as one of the Department's most critical energy issues [40,61,84,90,93]. The central role of petroleum products in DoD's energy mix is one of the most salient reasons why a large portion of ongoing efforts have focused on reducing DoD's use of petroleum through conservation, increased efficiency, and development and deployment of alternative fuel substitutes and technologies.

The US Defense Logistics Agency - Energy (DLA-E), formerly called the Defense Energy Support Center (DESC),⁴ is responsible for supporting the energy needs of DoD's combat operations, which includes the wholesale purchase, storage, and sale of fuels to DoD and other government agencies [94]. For operational energy use, the commodity cost of fuels purchased by DoD from DLA-E is often only a fraction of the total costs of energy for operational use. Significant indirect costs can be incurred by the logistical operations needed to transport and protect these fuel supplies from DLA-E supply points to DOE operational theaters, particularly when these theaters are in remote or politically unstable regions of the world. The "fully burdened cost of fuel" (FBCF), or the "fully burdened cost of energy" [95,96], varies widely depending on the location and distance of the transport operation and, especially, on the amount of force protection needed to guard the fuel supply convoys. One report estimated that water and fuel delivery accounted for 10-12% of historic casualties in Iraq and Afghanistan [87]. Schwartz et al. [90] provide a number of FBCF estimates collected from studies conducted by DoD Armed Forces:

"In 2010, the Marine Corps estimated the fully burdened cost of fuel in Afghanistan at between \$9 to \$16 per gallon if delivered by land, and between \$29 to \$31 per gallon if delivered by air. An Army study estimated the fully burdened cost of fuel in Iraq at \$9 to \$45 per gallon, depending on the type of force protection used to and the delivery distance, while an Air Force study estimated the fully burdened cost of fuel delivered by land at \$3 to \$5 per gallon and \$35 to \$40 per gallon

³ U.S. DoD's Fiscal Year 2011 is from October 1, 2010 to September 30, 2012.

⁴ From 2004 through 2008, the cost of DESC purchases from its supply network increased from \$5.9 billion to \$18.1 billion, a significant jump due almost entirely to increases in fuel prices. Over the same period, DESC sales to its customers increased from \$6.9 billion to \$18.7 billion. The DoD is overwhelmingly the DESC's largest customer, although the DESC sells a small amount of energy resources to non-DoD governmental agencies, as well as to foreign governments.

for aerial refueling. A report by the Army Environmental Policy Institute [87] estimated that the fully burdened cost of fuel for a Stryker brigade in Iraq ranged from \$14.13 to \$17.44 per gallon (\$3.73 to \$4.61 per liter)."

With fully burdened costs at this level we start to see one of the key reasons for the defense arena to be a key driver of technological innovation in energy systems. An economic case for new and initially at least, relatively high cost alternatives can be made much more easily in a defense context than in the lower cost world of civilian energy policy and markets.

Several industry and government reports (see e.g. Refs. [40,84,97]) have identified a critical need for DoD to develop measures to assess the indirect energy costs of technologies and systems, and to incorporate these measures into operational planning and acquisition processes. In doing so, DoD would be able to compare options on the basis of their energy performance and efficiency, along with other traditional factors, and make superior strategic acquisition, deployment, and R&D investment decisions.

However, it wasn't until 2007 that a policy memo published by the Office of the Under Secretary of Defense for Acquisitions, Technology, and Logistics (OSD (AT&L)) initiated the incorporation of fully burdened costs of energy considerations into acquisition decisions for three pilot programs. Following that, the Duncan Hunter National Defense Authorization Act (NDAA) for FY 2009, the military budget authorization bill passed by Congress in 2008, required the fully burdened cost of fuel and energy efficiency to be considered in planning, capability requirements development, and acquisitions processes.

With analytical guidance from the Defense Science Board's report, *More Capable Warfighting Through Reduced Fuel Burden* [40], OSD (AT&L) and the Office of Cost Assessment and Program Evaluation (CAPE) (formerly the Office of Program Analysis and Evaluation) have led the way by developing and refining guidelines for a prototype FBCF methodology. These guidelines have been incorporated into the Defense Acquisitions Guidebook, the DoD reference guide of best practices for acquisitions. Within the last decade, the Armed Services have adapted the OSD (AT&L)/CAPE methodology for their own use or developed similar methodologies.

Notions of cost minimization and economic efficiency are attractive to all defense departments and ministries, but acceptance of new more efficient technologies and practices by military personnel rely largely on a different logic. As discussed, recent asymmetric conflicts such as Iraq and Afghanistan have relied upon extended and vulnerable supply chains. This combines with the real and perceived isolation of forward operating bases to yield a sense among soldiers that they would prefer any approach that would reduce the need for fuel re-supply. Re-supply risks soldiers' lives and the lives of support workers in ways that would be avoided if more energy efficient systems were deployed. For the soldiers at the front, the need for frequent re-supply represents a vulnerability that they would prefer to avoid.

The analysis of alternative energy integration in the military found a focus in four areas of development:

- The area of liquid fuels continues to be an area of focus and vast potential. Most of the innovation in the area has involved the Air Force's and Navy's implementation of biofuel mixes. While there is skepticism regarding the economics of this work, the continued implementation and development of mixed fuel technologies has been ensured by legislation [98].
- Away from the front, military installations have received focus for the energy and cost saving potentials of efficiency and renewable energy systems. One estimate found that shifting from reliance on diesel backup generators to advanced microgrids at installations could save the DoD between \$8 billion and \$20 billion over the next 20 years [99].
- The imperative of maintaining power independence in forward operating bases has created demand for innovative systems. The

described difficulties of supplying fuel to generators have led to a number of unique efficiency modifications. This system has allowed for the development of more efficient microgrids for electrical power distribution on military bases and installations. These installations combine the smart information technology (IT) and environmental benefits seen in civilian equivalents together with enhanced IT security and with a strong emphasis on reduced fuel needs. Technological leadership in this space comes from US activity.

- The use of small-scale systems at the platoon/company level will continue to be developed and utilized as military leaders strive to provide small scale fighting forces independence from their fuel tether.

The growing momentum at the time within DoD and Congress to act regarding increasingly burdensome fuel logistics led to the establishment in 2010 of a new Assistant Secretary of Defense for Operational Energy Plans and Programs (ASD (OEPP)). The office was charged with developing DoD's first operational energy strategy and providing oversight and guidance to DoD agencies on operational energy. In 2011, the office released the *Operational Energy Strategy: Energy for the Warfighter* [100], followed by the companion *Operational Energy Strategy: Implementation Plan* in 2012 [101]. The report outlined three strategic goals:

- More fight, less fuel: reduce energy demand and increase energy efficiency
- More options, less risk: diversify energy sources and reduce dependence on external energy infrastructure, particularly the U.S. commercial electricity grid
- More capability, less cost: incorporate energy considerations into DoD institutions and processes, particularly for planning and acquisitions

The unique energy perspective of the military is also relevant in how technologies are shared amongst allied forces. Through foreign military sales, joint exercises and international basing, DoD can promote adoption of shared technical standards and directly influence the energy systems used by its allies [102]. The sharing of research and development and the constant push for standardization could lead to a beneficial dissemination of standardized new energy technologies to allied countries where the process of military technology pathways to commercial use can take place.

2.6. Energy decision-making for military installations

Energy is also consumed in the lighting, cooling, heating, communications, transport, and other energy services needed at defense installations. In FY 2011, DoD consumed 236 PJ (224 trillion BTU) of installation energy at a cost of \$4.1 billion [89]. Buildings accounted for 95% of consumption, while non-tactical vehicles made up 5%. Electricity and natural gas supplied the majority of installation energy (48% and 32%, respectively) [89], which was roughly analogous to the U.S. commercial sector's energy mix of 52% electricity and 38% natural gas in 2011 [88]. Worldwide, DoD manages more than 500 installations with around 300,000 buildings [89]. The DoD is required to construct and operate facilities consistent with minimizing life cycle costs, which often include energy and efficiency investments as program elements, however information gaps and other barriers remain [103]. The Army consumed the most installation energy (36% in FY 2011), followed by the Air Force (30%), and the Department of the Navy (28%), including the Marine Corps (DOD, 2012). All other DoD agencies accounted for the remaining 6%.

One of Former President Obama's first energy acts was enacting Executive Order 13514 on Federal Sustainability [104]. By issuing this order, the President made the government's "goal [to] lower costs,

reduce pollution, and shift Federal energy expenses away from oil and towards local, clean energy” [105]. The US Federal Governments internal goal of 28% reduction in GHG by 2020 has created greater emphasis within departments (DoD/DOE) to reduce fuel use and electricity, and permitted much energy technology research and development using federal resources. Here there are linkages to long-standing critiques from Europe that while the US tends to avoid political discourse on the themes of industrial strategy or industrial policy perhaps with a sense that such thinking is “un-American”. Critical Europeans have argued that such policy is alive and well in the US hidden within vast federal programs with other nominal missions, such as national defense.

Growing global awareness and action toward reducing greenhouse gas (GHG) emissions have led the U.S. federal government to implement several initiatives to reduce federal energy consumption and GHG emissions. These federal mandates have applied to the majority of DoD's vast array of fixed installations in the U.S. and abroad. Additionally, US DoD concerns about its reliance on commercial networks and infrastructure, particularly the U.S. electricity grid, have provided further impetus for energy innovation at its stationary facilities. Increasingly, fixed installations are directly engaged in operational missions in foreign theaters (for example through the command of unmanned aerial vehicles) as well as serve as local command centers for national relief and recovery efforts and Homeland defense missions. However, these installations rely heavily on a U.S. commercial electricity grid that is increasingly vulnerable to outages due to both accidents and intentional physical or cyber attacks [106]. Current methods of providing back-up power to installations are highly inefficient, costly, and fragmented [84].

While DoD's combat and tactical facilities, vehicles, and systems are largely exempt from these federal regulations, most of the agency's fixed installations and non-tactical vehicle fleets *do* fall under these regulations. And, in fact, they make up a very large proportion of federal facilities and fleets:

- In FY 2007, the total footprint and energy consumption (176 million m² and 216 PJ, respectively) of DoD buildings subject to federal energy reduction requirements was more than the total building footprint and energy consumption of all other agencies combined (102 million m² and 156 PJ, respectively) [107].
- In FY 2011, DoD fleet vehicles made up 30% of federal fleet vehicles and 24% of federal fleet fuel consumption (GSA Federal Fleet Report 2011).

Key requirements include:

- Produce or procure 25% of facility energy consumption by FY2025 (10 USC § 2911)
- Meters capable of recording energy consumption at least hourly and providing data at least daily installed in all federal buildings by October 1, 2012 (EPAAct 2005).
- A 30% reduction in energy intensity (energy consumption per gross square foot (gsf)) of federal buildings by FY 2015 using a FY 2003 baseline (EISA 2007, EO 13423).
- A 55% reduction in fossil fuel-generated energy consumption in new federal buildings by 2010, increasing to 100% reduction by 2030, compared to a similar building in FY 2003 (EISA 2007).
- Net zero energy consumption by 2030 for new federal buildings designed in 2020 or later (EO 13514).
- At least 7.5% of federal electricity consumption to be sourced from renewable resources by FY 2013. Renewable energy generated on-site or on other federal or Native American lands can receive double credit (EPAAct 2005).

Because of this, the federal mandates have initiated a flurry of activity by DoD component entities to develop and implement renewable

energy deployment strategies, build institutional capacity on facility energy management, and develop partnerships with other federal agencies as well as private sector organizations to fund energy research & development projects. Recent assessments of DoD efforts in both alternative financing for energy projects and energy saving contracts revealed the need for better data collection to measure and verify performance across the portfolio of projects [108,109]. Because of the number and scale of military energy projects, it is essential that performance data and project challenges be collected, so that both DoD and the civilian sector can learn from and improve upon these efforts.

The Deputy Under Secretary of Defense for Installations & Environment (DUSD (I&E)) office is responsible for managing military installation assets and services, including overseeing the installation of energy management programs and policies. At the request of Congress, the office released in 2005 the *DoD Renewable Energy Assessment Final Report*, which detailed the results of a study conducted to assess the potential to develop renewable energy resources on, or near, military installations, along with a companion Implementation Plan. Hence the DoD has initiated at considerable scale, a R&D and procurement activities across its portfolio of operational and installation energy uses. These investments have cascading impacts on innovation and the civilian energy sector.

US administrations change, and new administrations issue new defense policy priorities, and revoke or modify previous directives. The new National Security Strategy of the United States issued in 2017 stresses a posture of energy dominance and promoting energy exports, but also still highlights the importance of energy innovation and the need to balance energy security, economic development, and environmental protection [110]. As the energy requirements increase for dismounted soldiers, installations, and major weapons systems, so too will the relationship of energy to broader defense capabilities. Defense-led energy innovation will continue to be a driver of change in both the military and civilian sectors.

3. Conclusion

Energy has always been a strategic input to warfighting, but was typically viewed as the purview of logistics planners. Security, economic, and environmental factors have recently elevated energy to be considered as a system-wide strategic lever in the military, which will have lasting and positive results for war-fighting capabilities, and ultimately the civilian energy sector.

In this paper, we argued there is a long history of energy and defense interactions and these interactions apply in policy, strategy, and tactics. Furthermore, defense innovation has long led to civilian technological improvements in many technological areas, perhaps most notably in aerospace. We are now on the cusp of a possible similar technological transfer in the domain of energy technology. Defense can lead the way for economic reasons as well as a result of more direct military concerns. For example, for war-fighting in recent decades the US military has faced an extremely high fully burdened cost of fuel. Those very high costs favor moves to innovative approaches far earlier than would be seen in civilian contexts where prices and costs of established options are far lower. We recommend such questions for further research. We see these pressures in the defense context only growing further favoring defense-led innovation. Of course, non-state actors, belligerent states, and other adversaries may not value reduced environmental impacts or greenhouse gas emissions from military operations. But defense-led energy innovation from the U.S. and NATO member countries will only advance operational technologies and strategies that increase military capabilities, competitive advantages, and combat lethality in theaters of conflict. Hence efforts focused on improving environmental or energy performance of military activities could induce additional innovations in warfighting capabilities such as reduced logistics requirements or costs, resilient and low-signature off-grid power systems, or enterprise cost savings that adversaries are not

investing in nor benefiting from. In addition, more fuel-efficient major weapons systems and reduced logistics requirements can potentially partially offset some Anti-Access and Area Denial (A2/AD) efforts by adversaries. Finally, the recent emphasis on life cycle cost effectiveness and energy savings from installations will both reduce operating costs and enhance the resilience of these installations.

Alongside these developments, the issue of anthropogenic climate change has become a major international concern. While this paper does not directly concern itself with the impacts of a changing global climate on international relations, potential conflict, and military capabilities, there are clear points of interaction between this paper and that literature. This paper sees how climate change policies are affecting not only civilian innovation but also policy and decision making in defense contexts (nationally and inter-governmentally, such as in UN peacekeeping).

Military and defense innovations are now showing positive developments in the energy and environmental areas. Whether the changing nature of energy supply and use in military planning and tactics represents a revolution in military affairs remains an unanswered question, but we see the potential for a major shift emerging from the military arena where it may even achieve the status of a revolution in military affairs. We observe that there is an unhelpful separation, organizationally, and socially, between experts involved in civilian energy policy and innovation and their colleagues concerned about military strategy, planning, and capabilities. We suggest that those concerned about civilian energy technology and policy should do more to consider innovations and potential innovations emerging from the defense sector, and leverage two-way technology spillovers. We suggest there is a growing opportunity for a reverse flow (civilian to military) in energy innovation especially as one considers the greening of military operations. The advantages lie not just in looking at the present and the past, but also (where possible) into the future. These opportunities for mutually beneficial exchange have considerable potential to transform the ways both the defense and civilian sectors use and manage energy.

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